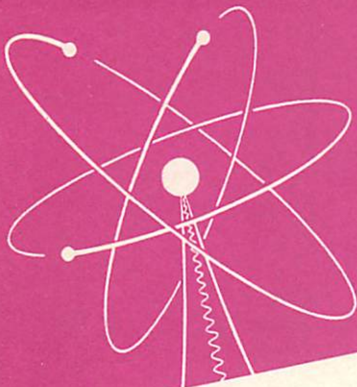
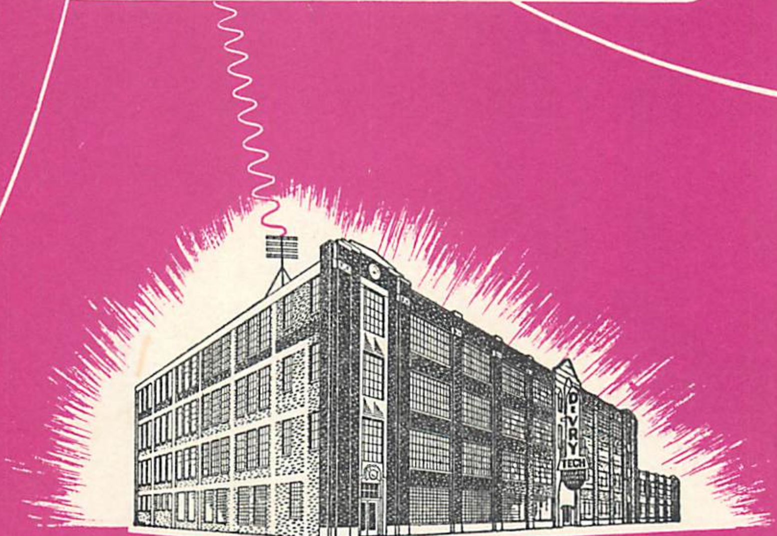


COLOR TELEVISION SIGNALS

Lesson T4E-8A



DeVRY Technical Institute
4141 W. Belmont Ave., Chicago 41, Illinois
Formerly DeFOREST'S TRAINING, INC.

E-8

T4E-8A

COLOR TELEVISION
SIGNALS

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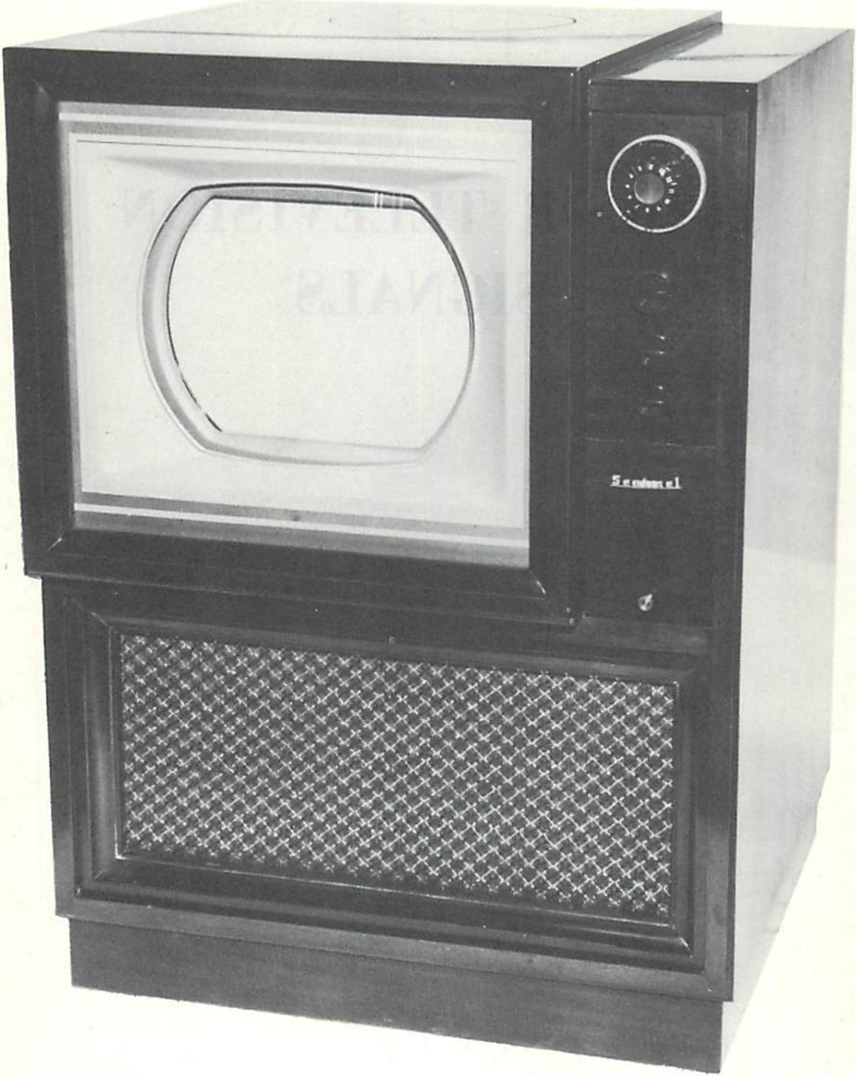


Color television receivers are operated as easily as black and white television sets. Controls added on the front panel adjust the intensity (saturation) of colors and color tones (hue) to appear most appealing to the viewer. Various servicing adjustments are located on the top of the television chassis and across the rear panel.

Courtesy Sentinel Radio Corporation

COLOR TELEVISION SIGNALS

Contents

PAGE

Color in Television 4

Color Broadcasting 10

Camera Chain 12

Operator's Console 15

The Chromacoder 16

Transmitter Matrix 17
  Luminance Signal 18
  I and Q Signals 18
  Narrow Band Signal 19

Subcarrier Modulators 19

Band Pass Filters 21

The Chrominance Signal 21

Color Synchronization 23

The Composite Signal 26

The Color Receiver 26

Color Reproduction 32

The Color Killer 33

Sweep Circuits 34

"Stripping away the blinders of distance and darkness, building a bridge across space, television is bringing the world right into your living room."

—General Electric Company

COLOR TELEVISION SIGNALS

No other specialized branch of electronics has demonstrated such an amazing development as television in the United States. In less than eight years since the beginning of the post war production, more than 25 million television receivers have been built for homes everywhere—more than 3 million television sets each year!

Perhaps no other manufactured product has received such unanimous acceptance wherever it has been introduced, television has become part of the nation's home because it has proven itself to be everything everyone expected. Now it offers still greater enjoyment for everyone.

Through television, we have been able to enjoy and appreciate many important events. Interest is stimulated as a vast audience, which extends in every direction across the nation, can see and hear important public affairs at the moment activity takes place. Each participant becomes a face as well as a voice and these individuals soon grow familiar to more people.

Formerly, our newspapers and magazines brought into the home a mute and graphic representation of leading persons. Motion pictures provided the only alternative for an in-person appearance.

Through the television medium, these individuals come into homes everywhere and with a natural ease and warmth that is not duplicated in radio, press, or motion pictures.

Television is always growing! UHF channels have fulfilled the possibility of television for population centers between principal large cities. Every day new stations go "on the air' with television for another community and a new demand develops for television receivers and for competent individuals to maintain the performance of these sets.

COLOR IN TELEVISION

While all this phenomenal growth and advancement continued, electronics and communications engineers, research physicists and chemists and a whole wide field of designers and technicians throughout the country cooperated to develop television in full, natural colors!

At first, a number of methods were evolved and each system displayed various shortcomings. None of these systems were compatible for black and white television sets. There is a vast number of receivers in use everywhere, but these systems had no ready provision whereby black and white reproductions could be seen.

Considerable modification would be required in these cases in order for present television receivers to be used with these systems.

Equally important was the fact that none of these early systems were capable of producing a color picture with comparable sharpness and detail as the present black and white receiver and still remain within the 6 mc standard channels established for monochrome transmissions.

All early color television systems offered these objectionable features as well as desirable achievements. However, valuable research data had been collected while developmental work was carried out on these color systems. Research representatives from all parts of the country met together and formed panels or study groups under the auspices of the National Television System Committee.

Among the objectives set up by this committee, the following were deemed very important:

(1) Complete compatibility between present black and white receivers and the proposed color television system.

(2) The new color system must keep within the standard 6 mc channel already established for TV broadcasts.

(3) The sharpness and details in the adopted system should be comparable to the existing black and white reproductions.

(4) The cost of the receiver must be within reach of the average pocketbook.

Each committee panel was assigned a specific problem. Some of the concepts soon developed by these panels and adopted by the committee are summed up under the following topics.

Two Signals

To assure compatibility between the black and white and color systems, two signals should be used. One signal, which is called the "Y", brightness, or **luminance signal,** should be as nearly like the present monochrome signal as possible and is to be used by both monochrome and color receivers. The second signal, which is called the "C" or **chrominance signal,** should contain all of the added color information needed for the color receiver.

Frequency Interlace

In order to have complete compatibility, not only must one of the signals be like the monochrome transmission, but the black and white receiver must not be affected visibly by the chrominance signal. Obviously, since the black and white signal is over five megacycles wide, it would be impossible for the two signals to be inserted side by side in a 6 mc channel, let alone to attain signal separation in a conventional monochrome receiver.

Fortunately, the black and white signal does not occupy a solid spectrum of 5.25 mc. In fact, the video energy occurs in energy packets at multiples of the horizontal sweep frequency each side of the video carrier.

The reason for this can be found in Figure 1A. As the scanning progresses from top to bottom every vertical line like A is crossed at the line frequency as scanning progresses through lines 101, 102, 103, etc. Diagonal lines like B are crossed slightly sooner on each scanning line and lines like C are scanned slightly later.

Therefore, all video pulses produced by these picture lines occur at or very near the line frequency and its harmonics as shown in Figure 1B. This leaves space between these sidebands into which added information can be inserted without affecting the picture. Such a process is called FREQUENCY INTERLACE and, as shown in Figure 1C, the color sidebands are placed midway between the black and white sidebands.

What is more important when considering compatibility, these interlaced sidebands do not have a visible effect on the monochrome receiver. Why this occurs can be seen by considering Figure 1D where A represents the scanning line frequency and B a frequency which is an odd harmonic (11th) of one half the line frequency A. Notice that as the line starts at (1) the odd harmonic swings into a positive alternation but at the beginning of the next line at (2) it swings in the negative direction. This reversal occurs with each line so that for all odd numbered lines the harmonic starts with a positive alternation and for all even numbered lines it is negative.

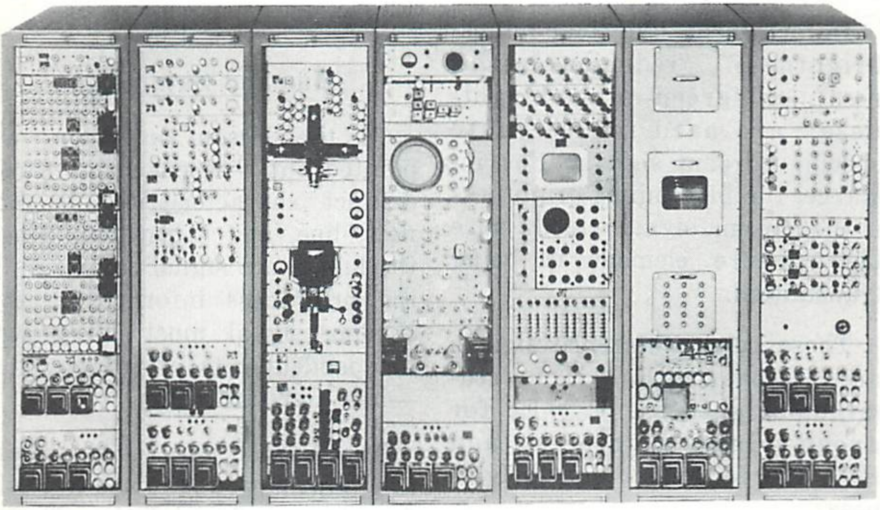
Notice that as one horizontal line starts at point (1), the odd harmonic begins on the positive alternation and ends at (2) on a positive alternation. As a result, the second horizontal line begins and ends with a negative alternation as indicated by the dashed line "C". Thus, in the first field all the odd numbered lines begin and end with a positive alternation while all the even numbered lines begin and end with a negative alternation. All together 525 lines are scanned in the first frame. Thus, the 525th line is an odd numbered line ending on a positive alternation.

Therefore, the 526th line which is the 1st line of the second frame has just the opposite phase as the first line of the first frame. This is shown by the dashed curve "C".

Due to the eye's persistence of vision, these rapid reversals tend to cancel out, making these odd harmonics practically invisible. Hence, by having the chroma signal modulate a carrier which is the 455th (odd) harmonic of the half line frequency, this chroma signal has little effect on the monochrome receiver and thus assures compatibility.

Surplus Signals

A basic rule to follow in the transmission of any signal is that if the senses cannot detect certain information, don't transmit it. This added information adds nothing and it can interfere with an essential signal. In color TV the luminance and chrominance signals were chosen to eliminate all surplus or REDUNDANT signals. Although very pleasing to the eye, the complete color TV signal is stripped of unnecessary signals in two ways.



Entire color television facilities are included in this rack-mounted unit. It furnishes color bar test signals and performs the operations of the colorplexer preparing color video information for the modulator in the transmitter rack on the right end. A vector scope, in the center rack, checks the phase relationships between the modulating signal components.

Courtesy Telechrome Incorporated

The black and white receiver detects only the luminance signal. Therefore, in order to receive a good picture on the black and white receiver, the complete brightness information must be sent in the luminance signal. However, any appearance of brightness in the chroma signal is unnecessary because the color receiver detects both signals. Therefore, the brightness signal is subtracted from the color signal for the chroma signal. Consequently, the chroma signal is frequently referred to as a COLOR-MINUS-BRIGHTNESS signal.

In fact, terms like "blue-minus-brightness", "red-minus-brightness", or "green-minus-brightness" are used to designate specific chroma signals. For instance, the blue-minus-brightness is the chroma signal when a pure blue picture element is being transmitted.

These color difference signals are designated as $E_R - E_Y$ for red-minus-brightness; $E_G - E_Y$ for green-minus-brightness, and $E_B - E_Y$ for blue-minus-brightness.

A second way to avoid redundance is not to transmit chroma signals which do not contribute to the picture quality. As we pointed out in a previous lesson on color, the eye does not see full color for small picture details. For tiny areas the color appears to be some brightness of a blue-green or an orange-red. In fact, for real small details no color is apparent and only brightness is seen by the viewer.

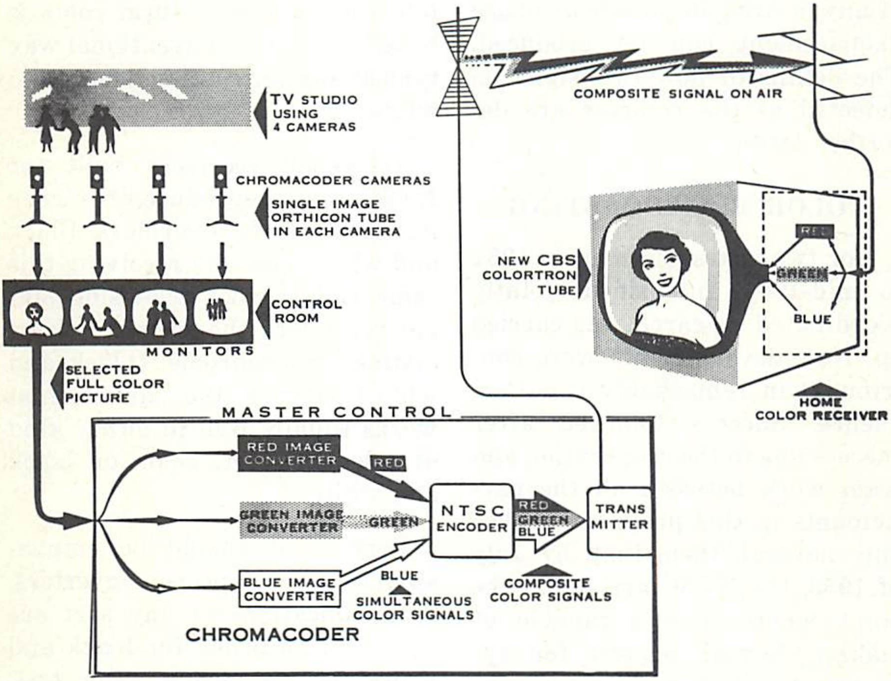
Considerable research along these lines showed that the eye sees, when viewing an average size picture tube from a normal distance, all the colors for TV picture areas generated by signals below .5 mc, two colors for .5 mc to about 1.3 mc, and black and white details above 1.3 mc. Therefore, it is pointless to transmit chroma signals at frequencies higher than 1.3 mc.

Hue and Saturation

In the lesson on color, we pointed out that color has three distinct characteristics: brightness, hue, and saturation. Since the luminance signal carries only the brightness information, the chroma signal must carry two independent bits of information —hue and saturation.

The easiest way to transmit this information is to use two different types of modulation. Therefore, the committee decided that the AMPLITUDE of the chroma signal would represent the saturation and the PHASE DISPLACEMENT of the chroma signal from some reference signal would determine the hue.

However, since direct phase modulation of the chroma subcarrier creates engineering problems, an alternative method was adopted where two subcarriers, of the same frequency but 90° out of phase, are modulated by two color-minus-brightness signals in balanced modulators. With suppressed carriers the resulting sidebands develop a chroma signal by vector addition which shifts in phase with change in hue.



Color television camera using a single image orthicon conveys sequential red, green, and blue images through the control room to the Master Control where these images are converted into compatible NTSC broadcast color television.

Courtesy Columbia Broadcasting System, Inc.

These two sets of sidebands are called the ORTHOGONAL COMPONENTS of the chroma signal. To distinguish between the two, one is called the "I" signal and the other the "Q" signal.

How this phase shift occurs may be seen by considering the vector diagrams in Figure 2. Where the I and Q signals are equal in amplitude, like Figures 2A and 2B, the resulting chroma vector C forms a 45° angle with Q. Therefore, since C differs only in amplitude, these two signals represent different saturations of the same hue. On the other hand the resulting chroma signal vector C of Figure 2C has the same amplitude as Figure 2B but has a different phase angle θ. Therefore Figures 2B and 2C have a different hue.

Finally, Figures 2A and 2C differ both in phase and amplitude and represent chroma signals of different hues and saturation. Consequently, by careful choice of I and Q signals, a chroma signal of any desired amplitude or phase displacement can be produced. The details of how this signal is detected at the receiver are described later.

COLOR BROADCASTING

For two years, from early 1951 to mid-1953, intensified, jointly coordinated research was carried on. New developments were contributed in remarkably rapid sequence. Success followed after success due to the cooperation and team work between all the participants in this program. It was only natural, then, that, by July of 1953, the NTSC arrived at the point where it was capable of making formal request for approval of and permission for commercial use of color television broadcasting based upon developed specifications which correspond in every respect with the limitations prescribed by the FCC. This request was adopted on December 17, 1953.

Compatibility

The NTSC color television is the culmination of the combined effort of the entire radio, electronic, and television industry. The specifications of the NTSC color television are wholly compatible with all black and white television broadcast receivers in use anywhere in the United States. Any program which is televised in full, natural color is broadcast in the conventional way typical for telecasting black and white.

Television receivers built for NTSC color reproduce the scene in beautiful life-like colors. Black and white receivers receiving this same NTSC color television signal reproduce the scene in clear, distinct monochrome (black and white). Hence, the same signal works equally well in either kind of television set, color or black and white.

Perhaps it should be emphasized that no adapters, converters, or modifications of any sort are necessary in order for black and white sets to receive color telecasts. These receivers will not reproduce a picture in colors, of course, but on the other hand, millions of television set owners will go right on and enjoy every popular program in the same way they enjoyed it in the past, although it may be televised in color from now on!

Compatibility does not end with the black and white television receivers. Television sets made for the NTSC color television signal reproduce a black and white picture with a conventional monochrome television signal.

Channel Width

Every part of the signal is kept within the same 6 megacycle television channel which was originally allocated for black and white telecasting. This became necessary at once when additional television channels in the UHF region were granted to assure future expansion of television service for every part of our nation. Nowhere in the authorized spectrum for commercial television broadcasting does sufficient space exist to allow a number of television channels wider than 6 mc!

Color Subcarrier

By frequency interlace color information is arranged to occupy space that exists between and separates small groups of monochrome video information. Therefore, a greater use is made of the 4.5 megacycle bandwidth between the picture and sound carriers in a television channel.

The color information is contained in subcarrier sidebands of the I and Q signals which occur at odd harmonics of one-half the television picture line frequency. These sidebands extend above and below the **color subcarrier** which is 3.579545 megacycles or, the 455th harmonic of one half the television picture line frequency; 15,734.264 cycles per second. Filters block all color information sidebands which would appear outside of the authorized 6 megacycle television channel.

The color subcarrier sidebands contain the color information which most nearly corresponds to the televised scene in terms of standard red, green, and blue primaries. The choice of these colors was determined entirely on the basis of mixtures which would match the widest selection of natural colors and tones. These primary colors are termed as additive primaries since sources of light for each of these colors are mixed in the correct amount to produce the desired color.

The video information which makes up the monochrome signal is composed of selected quantities of the red, green, and blue. The mixtures of these primary colors are selected to give natural picture reproduction on black and white receivers, since this monochrome video signal along with retrace blanking and the familiar horizontal and vertical synchronizing pulses, makes up a complete set of information for black and white television receivers.

A color subcarrier reference burst of nine cycles of 3.579545 megacycles is set on the blanking pedestal after every horizontal sync pulse; it is omitted during vertical retrace. Color television receivers require this reference signal, but since it occurs during blanking time, is not visible on either black and white or color television receiver screens.

This color television monitoring equipment performs the same operations as a color receiver. The I and Q signals are demodulated and mixed with the Y signal to produce a picture in color on the 15-inch tricolor picture tube.
Courtesy Polarad Electronics Corp.

Extensive field tests have been conducted in all aspects of the NTSC specifications to ensure full compatibility between black and white television and color television. From these tests, the frequency of the color subcarrier was determined and a nine-cycle (minimum, 8 cycles) color subcarrier reference burst was added.

Also, to minimize interference from the 4.5 mc intercarrier signal, the horizontal sweep frequency is changed slightly from the familiar 15,750 cycles per second to 15,734.264 cycles per second. This change requires a slight change in the vertical sweep frequency to about 59.94 cycles per second. Black and white television receivers have no difficulty adjusting automatically to these new frequencies since the difference is less than two-tenths of 1 per cent.

CAMERA CHAIN

A complete camera chain is shown as part of the transmitting station equipment in Figure 4A.

Figure 4B is another camera system using a slightly different approach. It is called a chromacoder, and when used, replaces the portion of Figure 4A enclosed in the heavy dashed lines on the left.

Possibly the best way to become acquainted with the NTSC Color System is to trace the signal step by step through typical transmitting and receiving equipment.

The camera in Figure 4A consists of an appropriate optical system which will divide a televised scene into separate images in terms of red, green, and blue colors. One type of camera employs a separate image orthicon for each color. Horizontal and vertical deflection circuits and a high voltage power supply are required for the image orthicons. An electronic view finder furnishes a black and white reproduction of the televised scene.

The camera control amplifier may be operated from a remote control console equipped with a master monitor. The camera signal shading correction, synchronizing pulses, camera blanking, and gain also are supplied from the control amplifier.

Optical System

The optical system in Figure 4A includes various objective lenses mounted on a rotating turret as shown in Figure 3, which can be changed quickly by the camera operator. A typical lens turret includes separate objective lenses for closeup views, middle distance scenes, and special wide-range and telescopic lenses.

Optical focus is adjusted by an operator's control handle. This control moves the turret and the position of the objective lens with respect to the condenser lens which remains stationary.

A relaying lens is used after the condenser lens. It increases the useful working distance in order to provide room for light-splitting dichroic mirrors, various astigmatism correcting glasses, and color trimming and neutral density filters.

An iris diaphragm is usually situated between the elements of the relaying lens. This is a variable aperture (opening) for correctly adjusting the amount of incoming light to the photocathode plates in the image orthicons. A selsyn motor in the camera is used to change the aperture size in the iris diaphragm. This selsyn is controlled from the video operator's console in front of the monitor.

The dichroic mirrors divide the televised scene into red, green and blue images. How this is done is shown in Figure 3. Light in colors of the televised scene arrives at the "blue" dichroic mirror. Here, blue colored light is reflected because the glass is specially made to reflect blue light and to pass all other colors. Thus, the blue color of the scene is reflected towards the "blue" image orthicon.

The remaining light passes through the "blue" dichroic mirror and arrives at the "red" dichroic mirror. Here, the red colored light is reflected toward the "red" image orthicon and the remaining green colored light passes through to the "green" image orthicon. Special red, green, and blue filters supplement the selectivity of the dichroic mirrors. These filters insure correct color rendering by absorbing all undesired colors and passing only those colors which furnish the desired results. These filters also correct for color characteristics and sensitivity differences which image orthicons display for different colors.

Two ground glass plates between the condenser lenses and the relaying lenses correct any astigmatism caused by the dichroic mirrors as light passes through them. The horizontal astigmatism corrector for the "blue" image orthicon adjusts conditions in order that red, green and blue light passes through the same total thickness of glass.

Neutral-density filters correct the relative sensitivity of each image orthicon so that transfer characteristics are more similar for each color. Filters are used with the "red" and "green" image orthicon. The "blue" image orthicon is favored to correct for artificially lighted scenes which usually exceed in yellow and red light.

Camera Controls

The camera operator has several useful controls available to him at the rear of the camera. Optical focus is adjusted by turning one of the camera control handles. These handles are used also to control tilting and "panning" movements as each scene requires.

The handle in the middle of the camera control panel is fastened by a long shaft to the rotating lens turret to permit ready change of lenses for different views.

Separate height and width controls are provided for each image orthicon in the camera. The voltage on the decelerator grid controls beam "splatter" and is individually adjustable. All these controls are included to provide proper registration of the red, green and blue pictures as each appears on the camera viewfinder.

Phone jacks also enable the camera operator to communicate with the video operator and the programming directors for technical supervision.

Viewfinder

An electronic viewfinder is mounted on the top of the color television camera. A black and white reproduction is obtainable of the "red" or "green" video superimposed on "blue" video, or all three video signals may be viewed simultaneously in order to align the objects of each picture and adjust each picture size to properly register with each other.

Aperture Compensation

Aperture compensation is inserted at the control amplifier to improve the picture detail by peaking and thus compensate for video amplifier phase shift, spot size in the image orthicons, and losses due to the use of coaxial cable from the camera. In this way, it is possible even to improve the resolution power of the lenses by changing the video frequency response of the electronic circuits of the camera.

The camera control amplifier is operated from the control console by the video operator. Here, brightness irregularities in the picture from each image orthicon are corrected by the shading generator output. Each video signal is amplified and blanking is set to proper reference level for insertion of synchronizing pulses.

Additional video high frequency peaking is used to compensate for losses due to long coaxial cable from the camera. Synchronizing pulses are brought into the control amplifier and also are amplified to operate the deflection circuits in the camera.

Gamma Correction

Unfortunately the receiver picture tube brightness is not directly proportional to the grid signal voltage. Doubling this grid voltage increases the brightness about four times. Although this is acceptable for monochrome reproduction, it must be corrected in color transmission systems for satisfactory color reproduction. The process of inserting an amplifier in the circuit with non-linear characteristics, which are equal and opposite to the picture tube and other circuit components which cause non-linear performance, is called **gamma correction.**

Without gamma correction added to the video signal voltages, flesh tones, for example, would vary in coloring all the way from a ruddy red-orange in a scene with subdued surrounding light to yellow-green in the midst of a very brightly lighted setting. Gamma correction ensures that correct flesh tones, and all other colors, appear most nearly natural no matter what prevailing light conditions may exist.

To correct this undesirable effect, the color video voltages are changed by an amount that is the reciprocal of this distortion which is $\frac{1}{2.2}$. In each case, the prime (′) is added to indicate the voltage represented is GAMMA CORRECTED. For example E_R' is $E_R^{\frac{1}{2.2}}$.

OPERATOR'S CONSOLE

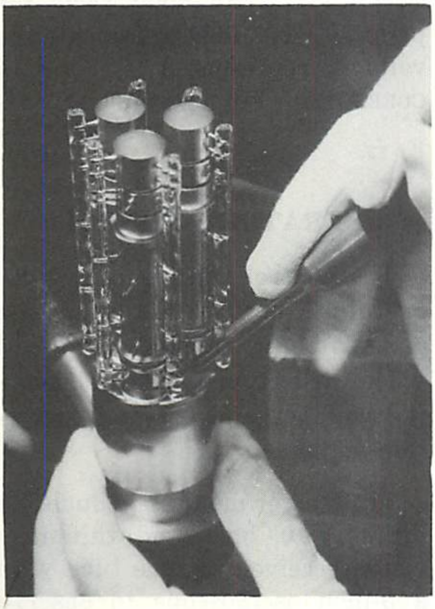
The control console is a video operator's position for adjusting or switching many important video, deflection and synchronizing voltages and shading correction voltages.

The master monitor includes an ordinary 10″ black and white television receiver picture tube with a 5-inch oscilloscope to observe video and synchronizing pulse wave shapes, etc. Here, as at the viewfinder of the camera, separate video signals may be selected or compared, or all three signals may be superimposed.

The monitor and its oscilloscope are used in close conjunction with the video operator's control console in order to maintain the correct camera operation and output at the control amplifier. Although there will be program monitoring carried on at a number of other places in a studio, the master monitor must be readily accessible for use by the video operator.

THE CHROMACODER

In the chromacoder of Figure 4B, the same type of optical system is used as Figure 4A except that, instead of dichroic mirrors, a rotating wheel made up of red, blue, and green color filters divides the televised scene into successive or sequential red, blue and green colors. Thus, the scene colors are transmitted very rapidly one after the other, and not simultaneously as in the camera of Figure 4A. This camera, therefore, requires only one image orthicon tube since it scans the scene a number of times to pick up the primary colors. In fact, this camera uses 180 fields, 60 red, 60 green, and 60 blue, and 47,250 lines per second.



Three electron guns are built side by side in the tricolor picture tube. Red, green, or blue video information, obtained from the color matrix, is applied to each electron gun.

Courtesy General Electric Co.

When the color wheel rotates its red, blue, and green filters past the image orthicon (IO) tube, the appropriate color field is produced at each of the three CRT's, fed by the CRT sweep generator. This is accomplished by feeding the camera signal through an aperture compensator and CRT drive amplifier. The gate and blanking generator provided with pulses from the camera allows the red CRT to be on only when the red filter is in front of the camera tube, the blue CRT only for the blue filter, and the green CRT is on only for the green filter.

Now the trick for converting these sequential signals into the NTSC simultaneous signals is performed by the cathode potential stabilized emitron tube

(CPSE). Since the red CRT is on $\frac{1}{180}$ second and off for $\frac{1}{90}$ second the CPSE phosphor reads the signal on red CRT for $\frac{1}{180}$ second. In contrast to its short reading time, the electric output is not only long, but continuous. Even though the CPSE has stopped reading, it continues to have an output voltage. Thus, each CPSE is emitting voltage continuously and hence simultaneous colors appear at the input to the control amplifier. The local CPSE sweep generator conforms to the FCC standards and so the fields and sweep output from these tubes is standard.

To avoid an uneven picture due to the CPSE scanning hitting and missing the lines on the CRT at random, the camera scanning and the CRT's use vertical lines. Thus, the CPSE horizontal scanning crosses over the vertical lines on the CRT at regular intervals and an even picture results.

Monitor switching and monitor unit are mainly for initial set-up conditions of camera and system. Optically, the main differences in the chromacoder system occur in the camera and in the lens between each CRT and CPSE. No dichroic mirrors, neutral density filters, nor astigmatism corrector are used in the camera. Between each CRT and CPSE is just an enlarging lens.

Essentially the camera controls are the same except that there are no registration controls. These are located at the control console, thus freeing the cameraman to concentrate on other important features.

TRANSMITTER MATRIX

As the three color video signals appear at the output of the gamma corrector, these signals are not satisfactory for TV broadcast. All of this video information requires a lot more than the authorized 6 mc channel width. Furthermore, not one of these three signals is suitable for any of the more than 30 million black and white television receivers!

Therefore, further operations must be performed on the "red", the "green", and the "blue" video signal after gamma correction. The first step is to obtain a monochrome video signal which is necessary for black and white television sets. This monochrome signal is the luminance signal used in color television receivers as defined by the FCC.

In addition to the monochrome signal, the two color signals, I and Q, are derived from the color video signals.

All three signals are special mixtures of the gamma corrected color video signals E_R', E_G', and E_B'. The mixtures are specific percentages of each color voltage purposely selected to provide a monochrome signal and to conserve video channel space.

The gamma corrected color video signals are combined in a group of specially arranged amplifiers and dividers to produce three new signals at the output of the **color matrix.** These three signals are expressed as percentages of the original three color video signals.

Luminance Signal

The percentages selected in the color matrix to make up the luminance or "Y" signal closely approximate the intensity the human eye observes in these colors. The human eye is most sensitive to green, the sensitivity to red is lower, and the eye is least sensitive to blue. Thus, the percentages were selected to make up a monochrome signal which would appear most natural on a black and white television set and this signal contains all the required picture fine detail.

To make up the **luminance signal,** 30 percent of the gamma corrected "red" video signal is selected. This percentage holds no matter what value the "red" signal voltage may be for a given picture element. To this is added in the color matrix 59 percent of all the gamma corrected "green" video voltage for that picture element and 11 percent of the gamma corrected "blue" video voltage. It is more convenient to express the luminance signal, E_Y', in mathematical terms, such as:

$$E_Y' = 0.30\ E_R' + 0.59\ E_G' + 0.11\ E_B'. \quad (1)$$

When E_R', E_G', and E_B' are all equal to each other, E_Y' is the luminance of white light! When any difference exists between E_R', E_G', or E_B', then E_Y' is the luminance of some color. Finally, when

$$E_R' = E_G' = E_B' = 0$$

E_Y' also is equal to zero, and this particular picture element is black!

From this it is possible to see how to obtain a shade of gray between white and black by choosing the proper amounts of color video signals to make up the luminance or monochrome signal. The luminance signal is considered, in a sense, in terms of the separate intensities of the three primary colors, and the resulting shade of gray on a monochrome receiver represents the light intensity of the particular picture element regardless of its color.

I and Q Signals

Two chroma signals which consist of special quantities of gamma corrected red, green, and blue color video voltages also are obtained at the output of the color matrix. These combinations transmit only information dealing with hue and saturation and, as mentioned before, are frequently referred to as color-minus-brightness signals. Called I and Q, these two chroma signals are defined by the FCC as:

$$E_I' = 0.60\ E_R' - 0.28\ E_G' - 0.32\ E_B', \qquad (2)$$

$$E_Q' = 0.21\ E_R' - 0.52\ E_G' + 0.31\ E_B'. \qquad (3)$$

Since all functions in the color matrix deal with gamma corrected red, green, and blue video signal voltages, no matter what operations are performed on these color video voltages, the result may be expressed in terms of the three primary color video signals as shown in Equations 1, 2 and 3.

The I and Q signals are each amplified in conventional video amplifiers and then applied to special low pass filters.

Narrow Band Signal

The E_Q' color video signal consists of the color information for the large picture areas and for video detail resolution between zero and 500 kilocycles.

In terms of picture resolution, this frequency response is confined to large color surfaces and coarse detail. Hence, its low pass filter has the lowest cut off frequency, 0 to 0.5 mc and its great attenuation to higher video frequencies also adds the greatest delay to the E_Q' signal, 1.4 μsecs.

The E_I' color video signal contains color information for a greater range of colors, from an orange-red through white to a blue-green for large picture areas and video resolution up to 1.3 mc, the semi-fine detail.

Since the frequency attenuation is not so great for the E_I' video signal, a 1.2 μsecs delay line is added so the signal does not arrive at the subcarrier modulator ahead of the E_Q' video signal.

The frequency response of the luminance signal is not restricted in any way other than by the limited overall response of the video amplifiers for the E_Y' video signal. Therefore, it becomes necessary to add a full 1.4 μsec delay to the signal in order that it does not arrive ahead of the I and Q signal sidebands at the adder circuit.

SUBCARRIER MODULATORS

Balanced modulators in the I and Q channels provide an odd harmonic sideband information output in order to make greater use of the 6 mc wide television channel with frequency interlace. The color subcarrier frequency is chosen to be the 455th harmonic of one half the horizontal frequency. Thus, sidebands of this subcarrier occur at the odd harmonics of half the line frequency.

Q Signal

Using the Q video signal to modulate a 3.579545 mc color subcarrier produces a series of groups of sidebands which contain the Q video signal. The feature of a balanced modulator exists in the fact that the original carrier signal is suppressed at the output. Only the necessary groups of sidebands are produced.

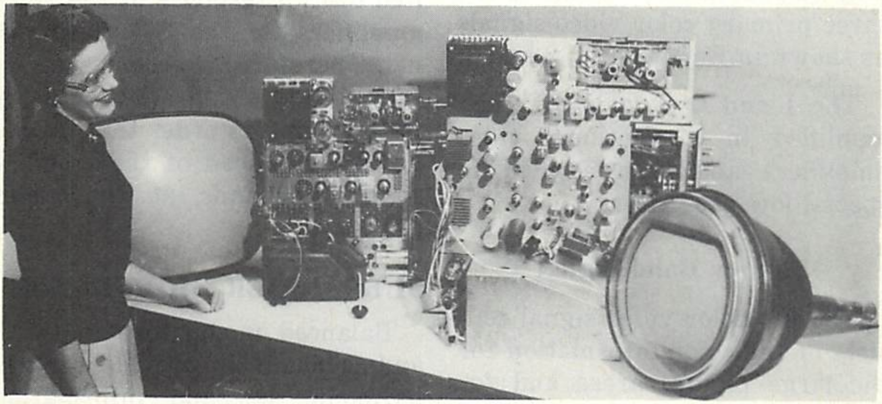
I Signal

The I signal is handled in a manner which is only slightly different from the Q signal. The same subcarrier frequency is used. However, before the subcarrier is modulated with the I signal, it is phase-shifted 90 degrees ahead of the subcarrier modulated by the Q signal. Thus, the I signal video sidebands occur 90 degrees ahead of the Q signal sidebands and, together, both share the space between the Y signal sidebands.

This must be a 90° phase shift, or an objectionable form of cross-modulation or interference develops between the Q signal sidebands and the I signal sidebands. Again, the phase-shifted subcarrier does not appear at the output of the balanced modulators.

D-C Restorers

Separate d-c restorers precede the input to the I and Q balanced modulators. Before modulation is applied to the separate subcarrier signals, the correct d-c reference level must be restored to the I



Color television receivers require additional circuits not necessary for a black and white television receiver. 31 tubes, including the 15-inch tri-color picture tube, are visible on the color chassis at the right, 21 tubes are visible in the black and white chassis at the left.

Courtesy General Electric Co.

and Q video signals. Just like monochrome television, conventional capacitive coupling between amplifier stages removes any d-c video reference which existed in the original color video signal at the output of the image orthicons in the camera. Therefore, some convenient means is used to restore this original d-c reference to the I and Q video signals before modulation takes place.

BAND PASS FILTERS

Band-pass filters are placed in the output of the balanced modulators. These filters remove the groups of sidebands higher than 4.2 megacycles generated during modulation. These sidebands must not extend beyond the authorized 4.5 megacycles between the television picture carrier signal and the sound carrier signal.

The I signal wide band pass filter removes sidebands which extend below 2 megacycles. This filter has an overall bandpass of 2.2 megacycles. Within this band, there are I signal video sidebands above and below the 3.579545 megacycle subcarrier.

This means that sidebands extend below the subcarrier, but not more than 1.6 megacycles below. Sidebands also extend above the subcarrier, but not more than 0.6 megacycles. These are VESTIGIAL sidebands, that is, of the sidebands which extend above the subcarrier frequency, only a part of these are retained. Sidebands higher than 0.6 megacycle above the subcarrier frequency would extend beyond the authorized channel, and, for this reason, must be filtered out.

The narrowband filter keeps the Q signal within the passband from 3 mc to 4.2 mc. Thus, the Q signal sidebands cannot extend more than 0.6 mc above or below the subcarrier frequency.

After modulation the I and Q signals are contained in two groups of side bands. When combined, these sidebands form the chrominance signal E_C'. Due to the fact that these sideband groups are 90° apart the resultant E_C' is both phase and amplitude modulated, and due to the manner in which the E_I' and E_Q' voltages were developed in the matrix, the amplitude of the E_C' represents the color saturation and the phase represents the hue.

THE CHROMINANCE SIGNAL

The I and Q signal modulation sidebands are the orthogonal components which make up the chrominance signal sidebands, E_C'. Finally the chrominance signal sidebands together with the luminance signal, E_Y', combine to make up the composite modulating signal, E_M. The mathematical expression which describes the amplitude of the modulating signal is given by FCC as:

$$E_M = E_Y' + E_C' \qquad (4)$$

where:

$$E_C' = E_Q' \sin(\omega t + 33^\circ) + E_I' \cos(\omega t + 33^\circ); \qquad (5)$$

$$E_I' = 0.60\ E_R' - 0.28\ E_G' - 0.32\ E_B'; \qquad (2)$$

$$E_Q' = 0.21\ E_R' - 0.52\ E_G' + 0.31\ E_B'. \qquad (3)$$

You may notice in these equations that both the I and Q signals have a 33° phase shift. This added shift was included in the standards to make it possible to design a "narrow band" receiver which reproduces the color broadcast in less detail but at a lower receiver cost. At the same time it doesn't add an appreciable cost to the standard "wide band" receivers.

The term "$\sin(\omega t + 33^\circ)$" in Equation (5) indicates a 33° phase shift of the E_Q' signal with respect to the phase reference, $\sin \omega t$, as shown in the vector diagram in Figure 5A. In the same sense, "$\cos(\omega t + 33^\circ)$" indicates a 123 degree phase shift of the E_I' signal, which is therefore 90° ahead of E_Q'. The I and Q signal carriers are phase shifted 33° before they're modulated. Thus, the color subcarrier for the Q signal sidebands is called "$\sin(\omega t + 33^\circ)$" and the color subcarrier for the I signal sidebands is called "$\cos(\omega t + 33^\circ)$"

The chrominance signal E_C', is best shown in how it contains color sideband information in Figure 5 by the use of vector diagrams. Each case describes the relative position of the chrominance signal vector for picture elements of given hue and the resultant length of the vector E_C' is determined by the saturation of the color to be transmitted.

White

White objects in a color television picture develop E_R', E_G', and E_B' color video voltages of equal amplitude as shown in column 1 of Chart 1. This is a special case where E_Y' indicates the luminance for white. Therefore, when white is to be transmitted, E_I' and E_Q', equal zero. No chrominance sidebands are sent and E_Y', the luminance signal, is all that is transmitted!

E_I' and E_Q' become zero again where black is transmitted, since E_R', E_G', and E_B' must equal zero; E_Y' also is zero for black.

Red

When the color of a given picture element is "pure" red; there is no green or blue in it. Therefore, in Figure 5A let us place this information in Equations (2) and (3) for E_I', and E_Q'. For convenience, the value for E_R' in each equation shall be assumed as 1. Then, the total E_Q' signal is equal to 0.21 E_R', or 0.21, and the total E_I' signal equals 0.60, since E_G' and E_B' equal zero in each equation and cannot add any signal to E_Q' or E_I'.

Adding these values for E_Q' and E_I', the amplitude of E_C' is determined by vectors to be 0.636, and its position with respect to the phase reference, sin ωt, is fixed when E_Q' is drawn, to its proper amplitude of 0.21, 33° ahead of sin ωt and E_I' is drawn to its amplitude of 0.60, 123° ahead of "sin ωt".

Yellow

The vectors in Figure 5B show the signal for transmitting yellow. Here assume E_G', E_R' each equal 1 while E_B' is zero. (To obtain yellow, equal amounts of red and green light are mixed). Now the result for E_I' is 0.32 and E_Q' is negative, or -0.31. The resultant amplitude of E_C' is 0.446. The vector to represent E_I' is drawn in the same position it was in for the "red" chrominance signal. However, the E_Q' vector is drawn in the opposite direction because it is a negative signal for yellow. E_Q' must be drawn 213° ahead of "sin ωt". The addition of E_Q' and E_I' now places E_C' in its new position for yellow.

Orange

For orange, where E_R' is 2, E_G' is 1, and E_B' is zero, the chrominance vector, E_C', lies between the "red" position and the "yellow" position. In fact, if E_G' were decreased to .8, E_C' would coincide with E_I' and E_Q' would be zero. This is shown in Figure 5C.

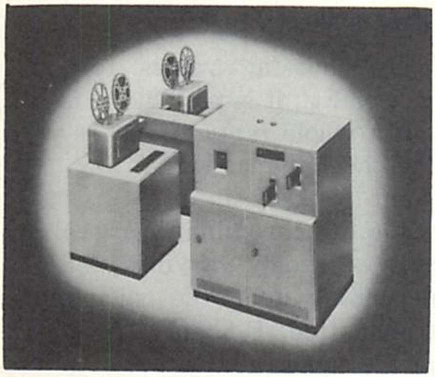
By choosing values for E_R', E_G', or E_B', it is possible to transmit a whole range of colors with the chrominance signal, E_C'. The point to keep in mind is, that while the chrominance signal occurs at widely varying positions depending upon the color to be transmitted, E_I' and E_Q' remain in the same relative vector phase and only change in amplitude or become negative, as each color may require.

The vector diagram of Figure 5H illustrates the various positions of the chrominance vector for different colors which can be transmitted for a given picture element. It shows the range of colors that may be transmitted and reproduced by the use of I and Q signal sidebands.

The color table in Figure 6 lists the various conditions which exist when different colors are transmitted. The values in this table correspond directly with the vectors used in Figure 5.

COLOR SYNCHRONIZATION

Although color television compares favorably in every respect necessary to be compatible with black and white television, additional color synchronizing information is necessary. In order that the chrominance sidebands, E_I' and E_Q' can be demodulated in the color television receiver, the receiver must generate a color subcarrier which is of correct frequency and phase.



Color motion pictures and slides may be televised in color by means of this scanning equipment. It is designed to provide red, green, and blue color video signals required for NTSC color television broadcasting.

Courtesy Allen B. DuMont Laboratories, Inc.

Since this subcarrier must be identical with the color subcarrier used for developing the I and Q signal sidebands, it is necessary to include a sample of the color subcarrier used in the colorplexer to be used as a frequency and phase reference for the subcarrier oscillator in the color receiver.

So that this reference signal does not interfere with the monochrome signal that must be furnished for black and white receivers as well as color sets, nine cycles of the 3.579545 mc are located on the blanking pedestal after the horizontal retrace time and the beam current in the picture tube is cut off during the interval.

Since the color subcarrier frequency is an odd harmonic of half the line frequency, color sidebands are so related that they occur at harmonics of the half-line frequency. In other words, were the choice of the subcarrier other than an odd harmonic, these color sidebands would be visible in the form of a maze of dots glittering all over the screen.

The choice of an odd harmonic makes it possible for the black and white receiver to eliminate this chrominance signal so it will not be an interference. Because these sidebands are at odd harmonics, each time a given line is scanned, these sidebands are phase inverted 180° as described for Figure 1D. This simply means then, that each time the line is scanned, the chroma sideband information will cancel the same information on that same line in the previous field. Persistence of the phosphor coating in the tube and persistence of vision along with the high range of frequencies (never below 2 mc) all tend to eliminate the visual effects of this chroma signal.

Burst

The **reference burst** in Figure 5A is obtained directly from the color subcarrier. The reference burst is defined by the FCC as $-\sin \omega t$. It is 180° out of phase with respect to the **phase reference,** $\sin \omega t$. The subcarrier is applied to a burst gate which is keyed by a burst pulse generator. Horizontal and vertical synchronizing pulses are applied to the pulse generator and, in this way, a keying burst pulse is developed which determines the proper interval for the reference burst.

The reference burst is initiated by the pulse generator and, after 9 cycles of the subcarrier have been sent, the burst is once again cut off until after another horizontal synchronizing pulse. This keying is repeated after every horizontal pulse until one complete field of lines is scanned. Then a special keying-out signal is supplied from the vertical synchronizing pulse amplifier which prevents the burst from being sent on the serrated vertical synchronizing pulses.

Sync Pulses

To assure good frequency interlace, the vertical and horizontal synchronizing pulses are derived from the color subcarrier generator by means of frequency dividers which "count down" the 3.579545 mc signal.

Briefly, a "divide-by five" oscillator reduces the subcarrier frequency to 715,909 cycles. This signal is applied to a "divide-by-seven" oscillator to produce 102,272.714 cycles. The frequency is then raised by a "times 4" multiplier to approximately 409,090.856 cycles. This frequency passes to a "divide-by-thirteen" oscillator to furnish approximately 31,468.528 cycles, to determine the frequency of standard equalizing pulses and serrated vertical synchronizing pulses. A "divide-by-two" oscillator brings the frequency down, then, to 15,734.264, the horizontal synchronizing pulse frequency.

Another series of frequency dividers reduces the 31,468.528 signal by factors of seven, five, five, and then three to furnish the 59.94 cycle vertical synchronizing frequency.

Adders

As indicated within the dashed block in Figure 4A, the sidebands of the I and Q signal modulated subcarriers are combined with each other to form the chrominance component of the color television signal. This is done by means of I and Q signal adder circuits. The chrominance signal is combined with the monochrome signal which also contains the horizontal and vertical synchronizing pulses. The reference burst is added here also.

The composite output of the adders is amplified and, after restoration of the correct d-c reference, the color television video signal is applied to the modulator in the television transmitter.

THE COMPOSITE SIGNAL

A brief description of the composite color television modulating signal also will explain some necessary phase shift relationships which must be maintained. The **composite modulating signal** is conveniently expressed mathematically by the FCC as:

$$E_M = E_Y' + \left[E_Q' \sin(\omega t + 33^\circ) + E_I' \cos(\omega t + 33^\circ) \right] \qquad (6)$$

E_M is the composite video signal for a particular picture element as it is applied to the modulator of the television transmitter. E_Y' is, of course, the gamma-corrected monochrome portion of the color video signal for the given picture element.

E_Q' and E_I' are amplitudes of the two orthogonal components of the chrominance signal for the given picture element.

It is interesting to note here that, when color video information above 500 kc is sent, the chrominance signal consists entirely of E_I', and the E_Q' signal becomes zero since it is limited to video information only up to 500 kc by a filter at the transmitter.

Below 500 kc, equation (6) can be expressed in terms of two primary color-minus-brightness components, that is,

$$E_M = E_Y' \frac{1}{1.14} \left(\frac{1}{1.78} (E_B' - E_Y') \sin \omega t + (E_R' - E_Y') \cos \omega t \right) \qquad (7)$$

The expression "sin ωt" in this last equation indicates that the $(E_B' - E_Y')$ component of the chrominance signal E_C' is in phase with the color reference "sin ωt". The notation "cos ωt" indicates that the $(E_R' - E_Y')$ component of E_C' is phase shifted by 90°.

Since Equations 6 and 7 both apply so long as the chrominance signal is below 500 kc, it is possible to build an economical receiver based on this equation which receives only the chrominance signal below 500 kc. How this narrow band receiver works is described later in the lesson.

THE COLOR RECEIVER

Emphasis on color television signal standards and a thorough familiarity of how the three primary colors are treated before being transmitted helps in describing the logical sequence the same signal is treated and restored in the color television receiver. The receiver is shown in block diagram form in Figure 7.

The object of the entire transmission system is to convert color into voltages which can be easily transmitted and received. Furthermore, the make-up of E_M determines how the receiver must behave for the most part to reconvert voltages to the original colors. In fact, a color TV receiver may be described as a transmitter in reverse. Starting with the composite signal the receiver breaks it up into the same signals developed by the camera and matrix in the transmitter.

Antenna and Tuner

The same antenna and tuner which are used for conventional black and white television sets may be used for receiving color television programs. Color television is entirely compatible for regular VHF or new UHF television broadcasting channels.

Existing television antennas that have furnished satisfactory incoming signal and reception to television receivers in the past perform equally well for receiving color television signals.

No special changes for color reception should be required except where prevailing local conditions demand special attention and this would, in all probability, be required in such cases for black and white reception also. For the record, it is emphasized that reception of color television signals compares, in every respect, with the same ease and the same problems which are so familiar for black and white television receivers and antenna installation.

Video and Sound I-F's

The video and sound channel in color television receivers compares exactly with conventional black and white television sets. For simplicity of design and most efficient r.f.-i.f. amplification, intercarrier i.f. sound amplification is used. However, separate germanium diodes may be used to detect the 4.5 mc sound i.f. and the video. The conventional discriminator or ratio detector is used to detect the audio.

Video Detector

The 2nd video detector output consists of the composite color television signal which was originally made up in the matrix; the I and Q sidebands, the reference burst, the monochrome, and the vertical and horizontal synchronizing pulses.

Y Channel

The luminance channel in a color receiver does exactly the same operation as familiar video amplifiers in black and white sets. A delay line is added to prevent the Y signal from arriving at the picture tube ahead of the I and Q signals which have a low-pass filter in each channel.

Band Pass Amplifier

The band pass amplifier is a typical pentode which amplifies the chrominance sidebands between 2.0 to 4.2 megacycles; all other video information is filtered out. The chrominance signal is applied directly to the I and Q signal demodulators. Here the sideband information is converted into E_I' and E_Q' color video signal voltages just like the E_I' and E_Q' output of the matrix in the transmitter colorplexer. A horizontal blanking pulse gates the band pass amplifier. Therefore, it does not pass the 3.579545 mc burst.

Color Demodulation

Up to here all color TV receivers have almost identical stages. The FCC, mindful of practical needs such as cost of a color TV receiver, made it possible to demodulate the transmitted signal directly in two ways: either the I and Q signals, or the color-minus-brightness B-Y and R-Y signals.

Referred to as a "wide band chrominance" receiver or just "wide band" receiver, one color TV receiver demodulates the I and Q signal. Since E_I is the wideband chrominance voltage, it is demodulated as is in the wide band color TV receiver. In contrast, a narrow band color TV receiver demodulates the color-minus-brightness signals B-Y and R-Y after the E_I' bandwidth is reduced to that of E_Q'.

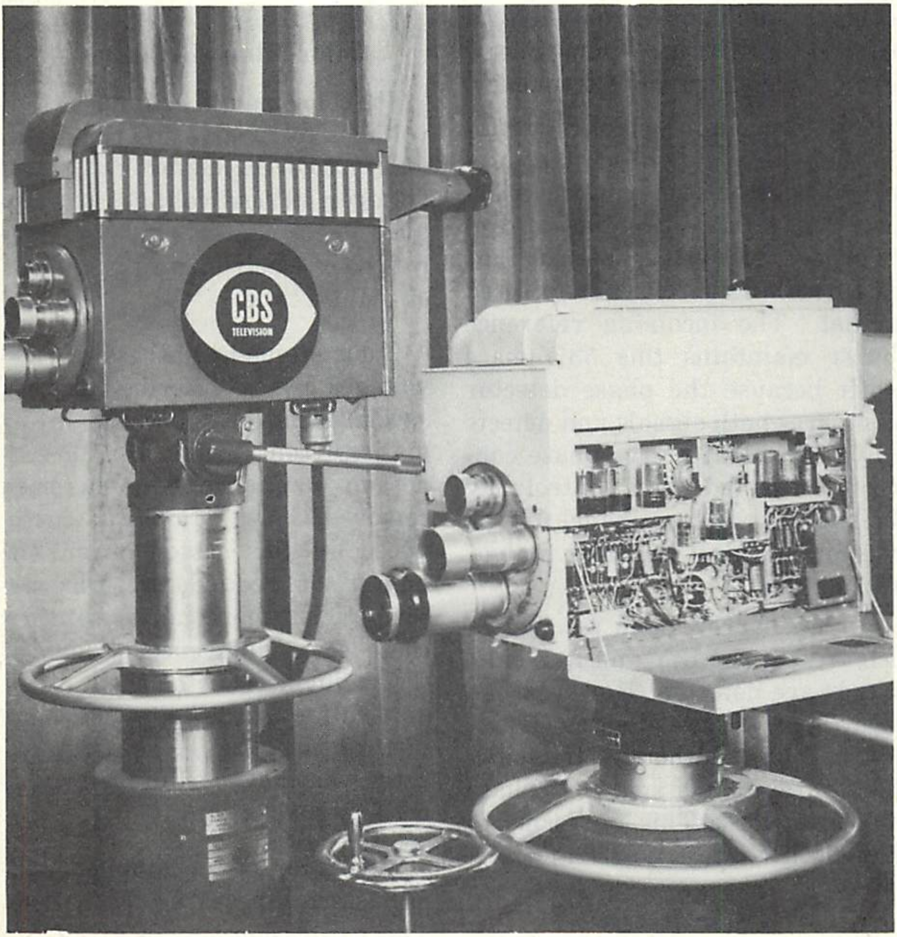
The local crystal oscillator provides a 3.579545 mc continuous wave signal which is phase shifted 33° and applied to the Q demodulator. Here, the Q signal sidebands are mixed with the cw signal and the E_Q' signal appears at the output of the demodulator. Before the phase shifted oscillator output can be applied to the I demodulator, it must be shifted in phase another 90° in order that it may properly mix with the I signal sidebands. The output of the I demodulator is E_I', the wideband chrominance signal.

Color Sync

An outstanding difference between a color television receiver circuit and the conventional black and white set is the additional "color synchronizing" section in the color set. The 3.579545 mc crystal oscillator and its control circuits make up the color synchronization.

Phase Detector

Since the local 3.58 mc oscillator replaces the absent color subcarrier, it is important to keep this oscillator in correct phase either for wideband or narrow band detection. The reference burst of nine cycles of 3.58 mc on the back porch of the blanking pulse helps maintain this local cw in correct phase for both types of receivers. First, let's examine the action in Figure 7A for the wideband color TV receiver.



The color television camera on the right is equally as compact and maneuverable as the standard black and white television camera. This color camera provides field sequential color television pictures which are converted to the NTSC color television signal. Only one image orthicon is required.

Courtesy Columbia Broadcasting System, Inc.

A sample of the local oscillator is applied to a phasing amplifier where it is passed to a phase detector. Here, the cw is compared with the reference burst. Any discrepancy develops an "error" voltage that is applied to an oscillator control amplifier. From here, a correction voltage immediately changes the oscillator frequency.

An important phasing control in the wide band chrominance receiver is associated with the phasing amplifier. When this control is properly adjusted, the oscillator is furnishing a 33° phase shifted signal. The incoming reference burst maintains this 33° phase shift because the phase detector compares both signals and detects any changes after the phase control is adjusted. This control may be used on the front panel for the viewer to adjust the color tone of the picture.

In the narrow band receiver of Figure 7C, the B-Y and R-Y sidebands are detected. However, notice the 3.58 mc cw signal is not shifted 33°, although the sidebands are kept 90° apart by a phase shift network. This conforms to Equation 7 where no 33° appears.

Color Matrix

Going back to the color matrix section of Figure 7A, the demodulated Q signal is filtered for correct narrow-band color frequencies, 0 to 500 kc. A Q signal phase splitter provides Q signal voltages of the proper amplitude and phase for the color matrix.

The same operations are performed on the I signal wideband color information from 0 to 1.5 mc.

Color-Minus-Brightness

The color matrix combines these voltages to furnish the three primary "color-minus-brightness" voltages. These voltages are applied to the control grids of separate color electron guns in the color picture tube.

Color-minus-brightness signal voltages can be described as very special forms of color video information from which the brightness or luminance value has been removed. This notion was introduced in this lesson when the matter of redundancy was described, but more can be said for these color difference signals at this point because of their direct application at the color television picture tube. Let us see first, exactly what a "color-minus-brightness" signal is.

Take, for an example, "red-minus-brightness," or $(E_R' - E_Y')$. This expression may be given in a more useful form by substituting Equation (1) for E_Y' and then solving the new expression in terms of E_R', E_G', and E_B'.

$$\begin{aligned}(E_R' - E_Y') &= E_R' - (0.30\ E_R' + 0.59\ E_G' \\ &\quad + 0.11\ E_B') \\ &= 0.70\ E_R' - 0.59\ E_G' - 0.11\ E_B'\end{aligned}$$

By the same method, an expression which describes "green-minus-brightness" may be obtained.

$$(E_G' - E_Y') = E_G' - (0.30\ E_R' + 0.59\ E_G' + 0.11\ E_B') = 0.41\ E_G' - 0.30\ E_R' - 0.11\ E_B' \quad (9)$$

The purpose for giving these two equations is to emphasize the relation between the "color-minus-brightness" video signals and regular color video voltages E_R', E_G', and E_B'.

"Blue-minus-brightness" is determined the same way. It too, is derived from the E_Y' equation.

$$(E_B' - E_Y') = 0.89\ E_B' - 0.30\ E_R' - 0.59\ E_G' \quad (10)$$

The color matrix in the color television receiver combines specific quantities of I and Q signal voltages which have been obtained from the demodulators and produces these primary "color difference" signals just described. These voltages from the color matrix are applied to the control grid of the separate color designated electron guns in the color picture tube.

Adders

Special combinations of E_I' and E_Q', shown on the receiver block diagrams of Figure 7, are required in order to obtain the desired "color difference" signals.

In the transmitter matrix, the output voltages E_Y', E_I', and E_Q' are formed by combining fixed portions of the input voltages E_R', E_B', and E_G'. Therefore, in the receiver, a reverse matrix operation is employed. Fixed portions of E_Y', E_I', and E_Q' must be added together to produce E_R', E_B', and E_G'.

For the wide band receiver of Figure 7A the matrix action is pictured by Figure 7B. To produce E_R', 1.0 E_Y', .945 E_I', and .621 E_Q' are combined into one voltage. In like manner 1.0 E_Y', −1.11 E_I', and 1.72 E_Q' form E_B', and 1 E_Y', −2.71 E_I', and −.647 E_Q' produces E_G'.

Finally each of these voltages is applied to the appropriate control grid on the picture tube as shown in Figure 7A and the colors are reproduced on the screen.

In a narrow band receiver the E_R', E_B', and E_G' voltages are produced in a slightly different manner. The block diagram for this narrow band receiver is like the wide band receiver except that the blocks shown in Figure 7C replace the portion outlined with a dashed line in Figure 7A. Now the detectors produce $E_R' - E_Y'$ and $E_B' - E_Y'$ instead of E_I' and E_Q'. Therefore, to get the three voltages, E_R', E_B', and

E_G' between the appropriate grid and cathode two steps are taken. First a simple matrix is used to form $E_G' - E_Y'$.

As shown in Figure 7D adding $-0.19\ (E_B' - E_Y')$ and $-0.51\ (E_R' - E_Y')$ produces $E_G' - E_Y'$.

Now all three of these color difference signals are applied to the appropriate grid. However, this is not the complete story, since it is the color signal and not the color difference signal that produces the proper color on the screen. Therefore, the $-E_Y$ signal must be inserted at the picture tube cathode. Since a negative signal on the cathode is the same as a positive signal on the grid, between each grid a color signal is produced by adding the E_Y' signal to the color difference signal. For example, $E_G' - E_Y' + E_Y'$ gives E_G'.

COLOR REPRODUCTION

With these various steps in mind it would be very helpful to trace several colors through this color system to see how they affect the signals and reappear on the receiver screen. To do this bear in mind the following signals are developed by the transmitter matrix in Figure 4:

$$E_Y' = .30\ E_R' + .59\ E_G' + .11\ E_B' \qquad (1)$$

$$E_I' = .60\ E_R' - .28\ E_G' - .32\ E_B' \qquad (2)$$

$$E_Q' = .21\ E_R' - .52\ E_G' + .31\ E_B' \qquad (3)$$

To further simplify this problem let us assume that the voltage developed by the camera is the same level required by the picture tube. If more is needed, equal amplification can be added to each channel.

White

For white light let's assume our camera puts out 4 v for each color as shown in column 1 of Chart 1. By using the FCC equations, E_Y' is also 4 v. Subtracting the brightness voltage from each color, all the color differences voltages are zero. E_I' and E_Q' are also zero, therefore the chrominance voltage E_C' is zero.

Gray

For a gray of exactly $\frac{1}{2}$ the luminance of white for case 1 of Chart 1, each voltage is 2 v, hence, $E_Y' = 2$ v. Again, all the voltages below E_Y' in column 1 are zero.

Red

For a red object at a given level of illumination, the camera output is given by the first three lines in column 2 of Chart 1 as:

$$E_R' = 4\text{ v} \qquad E_B' = E_G' = 2\text{ v}$$

Therefore, each of the remaining voltages can be computed by using the FCC equations. The results also are listed in column 2.

Suppose the object scanned has the same saturation and hue, but twice the luminance. Its component gamma corrected color voltages R, G, and B are 8.0 v, 4.0 and 4.0 as shown in the third column. Then, E_Y' is 5.2 v or twice the previous luminance voltage of 2.6 volts. Notice that the color difference voltages, the I and Q vectors, and the chrominance vector C all are exactly doubled.

The saturation remains constant because an increase in luminance voltage E_Y' was followed by an equal increase in chrominance voltage E_C'. Another way to say the same thing is that saturation of one color is the same as that of another color when the ratio E_C'/E_Y' is the same.

Since $\frac{1.3}{2.6}$ and $\frac{2.6}{5.2}$ are both equal to $\frac{1}{2}$ as shown by the next to last line, the saturation is the same for this hue. The hue also remains constant. This is indicated by the same ratio for E_Q'/E_I'. That is, $\frac{.42}{1.2}$ and $\frac{.84}{2.4}$ are both equal to $\frac{7}{20}$

In column 4, a still brighter red has more luminance than the red of column 3 because the luminance voltage E_Y' has increased from 5.2 volts to 6 volts. However, the hue is the same and the saturation of the color is reduced. These are indicated by the fact that E_Q'/E_I' is the same and E_C'/E_Y' has reduced.

Column 5 on the other hand shows the same red hue luminance as column 2 but with an increase in saturation as shown by the changed ratio. These facts are indicated by the hue ratio and E_Y' remaining the same although the saturation ratio changes.

Finally in column 6 is a blue-green color with a hue the complement of the red shown in columns 2 through 5. Notice that the hue ratio is the same but E_Q' and E_I' are now negative numbers.

These six colors have pointed up some important ideas to be kept in mind while servicing color TV receivers. They are:

(1) that for a white, $E_I' = E_Q' = 0$ v.

(2) the luminance can remain constant, while the hue and saturation change.

(3) that the hue changes when the E_Q'/E_I' ratio changes.

(4) saturation changes when E_C'/E_Y' changes.

THE COLOR KILLER

The color television receiver will reproduce standard black and white television broadcasts as readily as standard black and white television receivers. To do this, when a black and white television broadcast is received, a special "color killer" circuit in wide band receivers provides a cut-off bias voltage at the grid of the band pass amplifier. Then, no signals are applied to either the I or Q channel in the color receiver. In narrow band receivers, this circuit functions to prevent any signal from appearing in the R−Y and B−Y channels.

Black and White Pictures

The standard black and white video information is amplified in the luminance channel from the composite video amplifier. The black and white video is applied, in correct picture phase, to the cathode of the color picture tube and appears as a black and white picture on the screen.

A positive voltage from the horizontal output transformer initiates conduction in the color killer amplifier which, in turn, applies a cutoff voltage to the band pass amplifier.

Color Pictures

When color video is being received, a cut-off voltage from the phase detector is applied to the grid of the color killer, and when the color killer is at cutoff, the band pass amplifier conducts and amplifies the incoming I and Q signals.

SWEEP CIRCUITS

The horizontal and vertical sweep circuits in a color receiver operate in precisely the same manner as sweep circuits in conventional black and white television receivers. Conventional vertical and horizontal free-running blocking oscillators may be used.

Incoming synchronizing pulses are obtained from the composite video amplifier and applied to appropriate sync separator and amplifier circuits. Like in monochrome receivers, these maintain the frequency of the sweep oscillators in sync with the incoming video signal.

Oscillators

The sweep oscillators furnish the proper sweep drive required for the vertical output amplifier and the horizontal output amplifier just as it is done in any black and white television receiver.

Sweep Output

The vertical output amplifier is transformer coupled to the vertical deflection coils and, with the familiar horizontal output transformer, the horizontal output amplifier is coupled to the horizontal deflection coils.

High Voltage

The 20 kv anode voltage is developed in the conventional way. The most efficient of course, is the "flyback" type system with high voltage rectifiers, in a doubler arrangement when it may be required to obtain relatively high anode voltage.

Dynamic Convergence

Color picture tubes require some special deflection care which was not necessary in black and white picture tubes. When a three-gun picture tube such as is shown on the block diagram, is used each electron beam must arrive at the same "triad" of color dots; the beams must meet and cross over at the same point on the shadow mask. Adjustment is made for "d-c convergence" at the center of the screen. Then, both vertical and horizontal "dynamic convergence" furnishes an instantaneous convergence correction as the three beams are deflected over the many different picture elements. Dynamic convergence prevents the beams from diverging as the tube is swept over the entire area of the picture tube.

Focus Rectifier

The focus rectifier obtains a high voltage pulse from the horizontal output transformer. The pulse is rectified and filtered and applied to the focusing anode in the color picture tube.

Keyed AGC

An agc amplifier is useful to counteract undesirable changes in incoming signal level. A filtered d-c control voltage is applied to the grid of the agc amplifier. This voltage, proportional to the amplitude of horizontal synchronizing pulses at the sync separator, may be adjusted for best performance. A positive pulse from the horizontal output transformer provides the positive plate voltage; the plate is "keyed" at the horizontal frequency. The output of the agc amplifier is filtered and a negative control voltage is applied to the tuner and the video i-f amplifiers.

The subsequent lessons concentrate on the specialized circuits which may be found in color television receivers. The aim in this lesson has been to follow the signal from camera to picture and see what is needed in the way of special circuits. In the next lesson we shall describe some of these circuits.

* * *

IMPORTANT DEFINITIONS

CHROMINANCE SIGNAL—[KROH mi n'ns SIG n'l]—(C)—The hue and saturation of the reproduced picture element added to the brightness signal to make up the composite. It is color video information.

$$E_C' = E_Q' \sin(\omega t + 33^\circ) + E_I' \cos(\omega t + 33^\circ).$$

COLORPLEXER—The complete equipment at the transmitter that enables the outputs of the camera tubes to be mixed properly with the 3.58 mc oscillator signal to form the chrominance signal.

COLOR BURST—See Reference Burst.

COLOR MATRIX—[KUHL er MAY triks]—An array of mixing circuits arranged to select a certain percentage of input signals to produce the desired output signals.

COLOR SUBCARRIER—The 3.579545 mc carrier, modulation sidebands of which are combined with the brightness signal to make up the composite color signal: $\sin \omega t$.

COMPOSITE COLOR SIGNAL—The complete color signal including the monochrome signal, chrominance sidebands, blanking, and all synchronizing signals as

$$E_M = E_Y' + [E_Q' \sin(\omega t + 33^\circ) + E_I' \cos(\omega t + 33^\circ)].$$

D-C CONVERGENCE—[dee see k'n VERJ 'ns]—The electrostatic correction required in order that the electron beam from each color gun meet at the same point at the center of the shadow mask in the color picture tube.

DYNAMIC CONVERGENCE—[digh NAM ik k'n VERJ 'ns]—The correction required during vertical and horizontal deflections in order that the electron beam from each color gun meet at the same point on the shadow mask, cross over each other, and arrive at the same "triad" of color phosphor dots on the picture tube faceplate.

IMPORTANT DEFINITIONS—(Continued)

GAMMA CORRECTION—[GAM uh kuh REK sh'n]—An exponential correction of E_R, E_G, and E_B at the output of a color television camera in order to compensate for non-linear fluorescent characteristics of picture tube phosphors. It is indicated with a prime (′); i.e., E_R', E_G', E_B', etc.; which represents an exponent which is the reciprocal of 2.2.

I SIGNAL—One of the orthogonal sideband components produced by modulating the 3.579545 mc subcarrier with E_I' after the subcarrier is phase-shifted 123°; $E_I' \cos(\omega t + 33°)$.

LUMINANCE SIGNAL—[LOO mi n'ns SIG n'l]—(Y)—The monochrome part of the composite color video signal which determines the luminance of color television pictures, and which provides the picture for standard black and white television sets. It is defined by the FCC as:

$$E_Y' = 0.30\ E_R' + 0.59\ E_G' + 0.11\ E_B'.$$

PHASE REFERENCE—A particular phase of the color subcarrier frequency which is used as a reference point.

Q SIGNAL—One of the orthogonal sideband components produced by modulating the 3.579545 mc subcarrier with E_Q' after the subcarrier is phase shifted 33°; $E_Q' \sin(\omega t + 33°)$.

REFERENCE BURST—Nine cycles of 3.579545 mc, phase inverted with respect to the phase reference, and transmitted after each horizontal synchronizing pulse during horizontal retrace blanking. The reference burst is not transmitted during vertical retrace.

TRIAD—[TRIGH ad]—A group of three color phosphor dots arranged in an equilateral triangle and consist of one red-emitting dot, one green-emitting dot, and one blue-emitting dot.

STUDENT NOTES

STUDENT NOTES

STUDENT NOTES

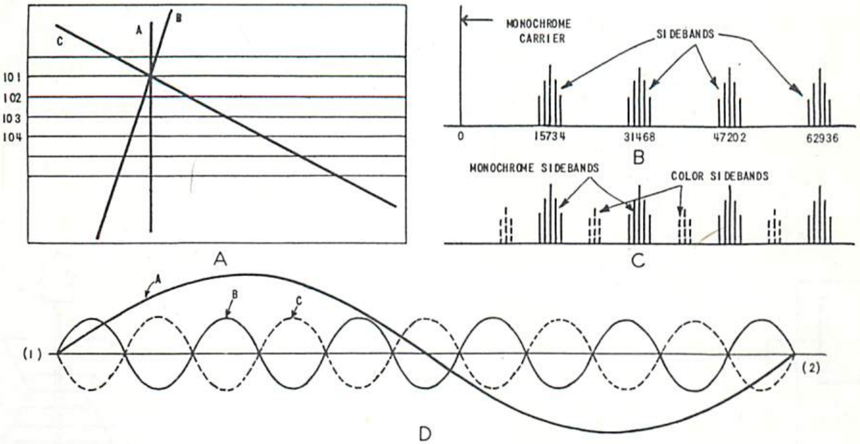


FIGURE 1

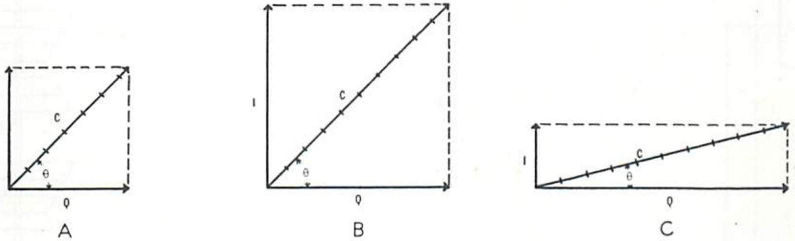


FIGURE 2

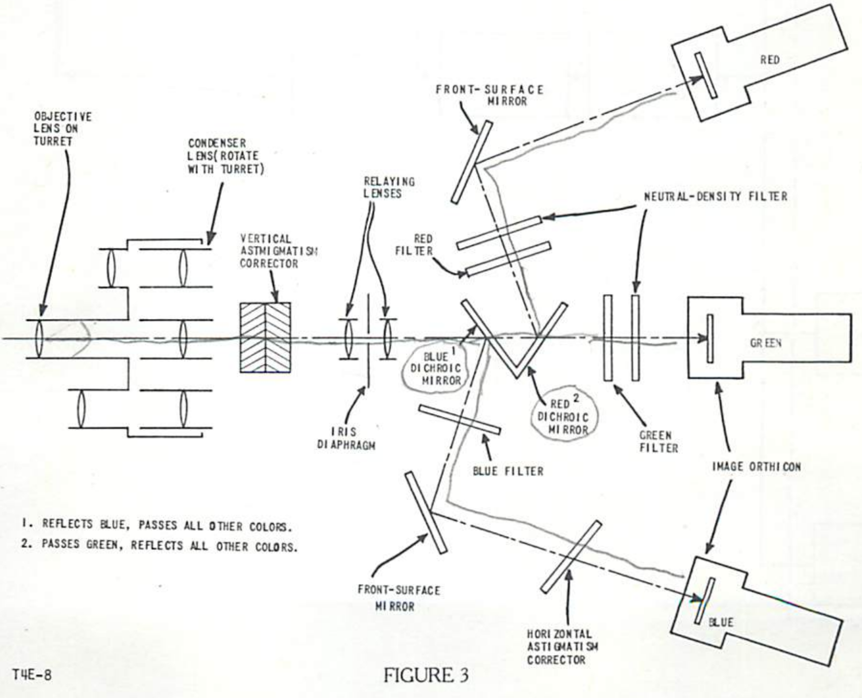


FIGURE 3

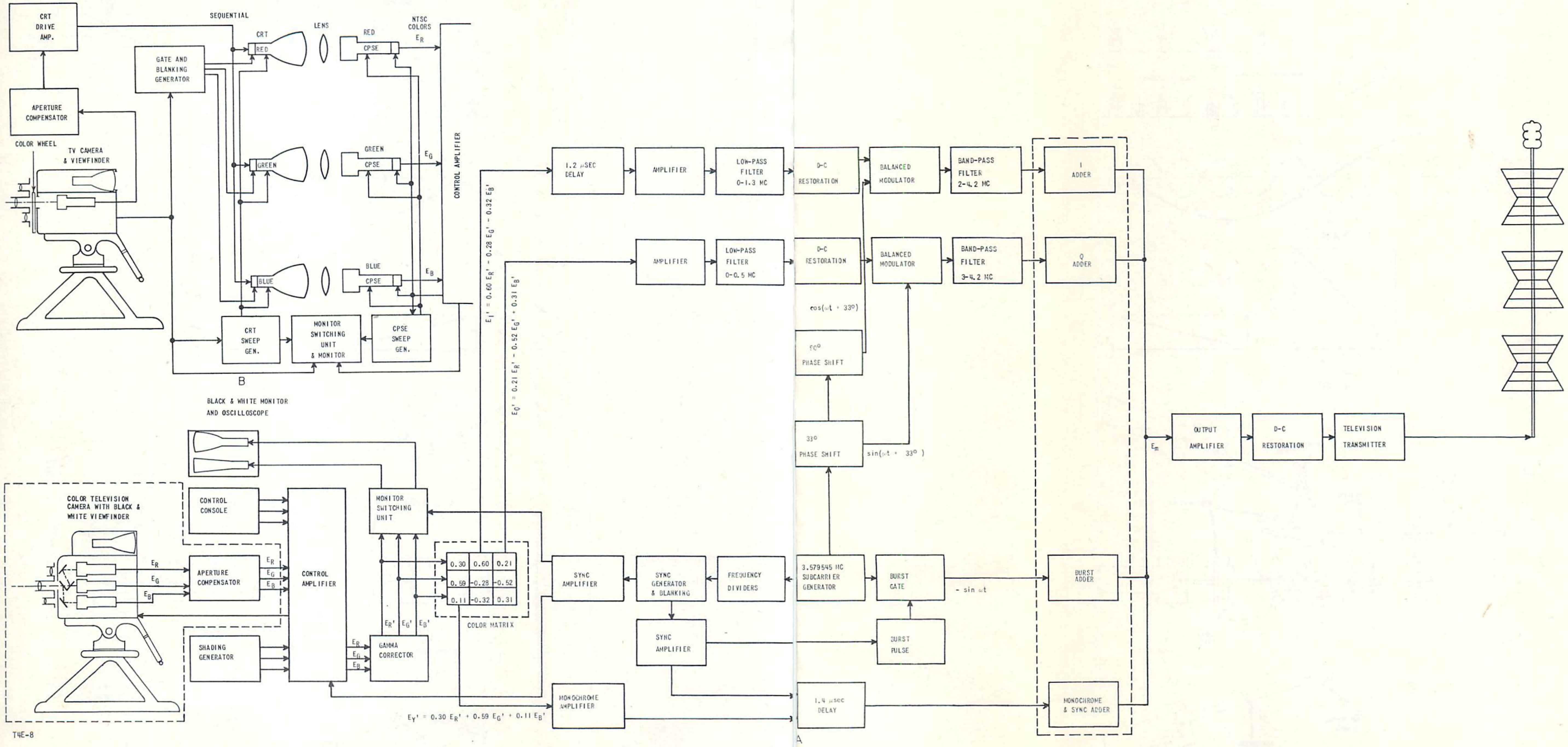

CRT DRIVE AMP.
APERTURE COMPENSATOR
COLOR WHEEL
TV CAMERA & VIEWFINDER
GATE AND BLANKING GENERATOR
SEQUENTIAL
CRT
RED
GREEN
BLUE
LENS
NTSC COLORS
CPSE
E_R
E_G
E_B
CONTROL AMPLIFIER
CRT SWEEP GEN.
MONITOR SWITCHING UNIT & MONITOR
CPSE SWEEP GEN.
B
BLACK & WHITE MONITOR AND OSCILLOSCOPE
COLOR TELEVISION CAMERA WITH BLACK & WHITE VIEWFINDER
CONTROL CONSOLE
APERTURE COMPENSATOR
CONTROL AMPLIFIER
SHADING GENERATOR
MONITOR SWITCHING UNIT
GAMMA CORRECTOR
E_R' E_G' E_B'
0.30 0.60 0.21
0.59 -0.28 -0.52
0.11 -0.32 0.31
COLOR MATRIX
$E_Y' = 0.30\ E_R' + 0.59\ E_G' + 0.11\ E_B'$
$E_I' = 0.60\ E_R' - 0.28\ E_G' - 0.32\ E_B'$
$E_Q' = 0.21\ E_R' - 0.52\ E_G' + 0.31\ E_B'$
1.2 μSEC DELAY
AMPLIFIER
LOW-PASS FILTER 0-1.3 MC
LOW-PASS FILTER 0-0.5 MC
D-C RESTORATION
BALANCED MODULATOR
BAND-PASS FILTER 2-4.2 MC
BAND-PASS FILTER 3-4.2 MC
I ADDER
Q ADDER
$\cos(\omega t + 33°)$
90° PHASE SHIFT
33° PHASE SHIFT
$\sin(\omega t + 33°)$
SYNC AMPLIFIER
SYNC GENERATOR & BLANKING
FREQUENCY DIVIDERS
3.579545 MC SUBCARRIER GENERATOR
BURST GATE
$- \sin \omega t$
BURST ADDER
BURST PULSE
MONOCHROME AMPLIFIER
1.4 μsec DELAY
MONOCHROME & SYNC ADDER
E_m
OUTPUT AMPLIFIER
D-C RESTORATION
TELEVISION TRANSMITTER
A
T4E-8

FIGURE 4

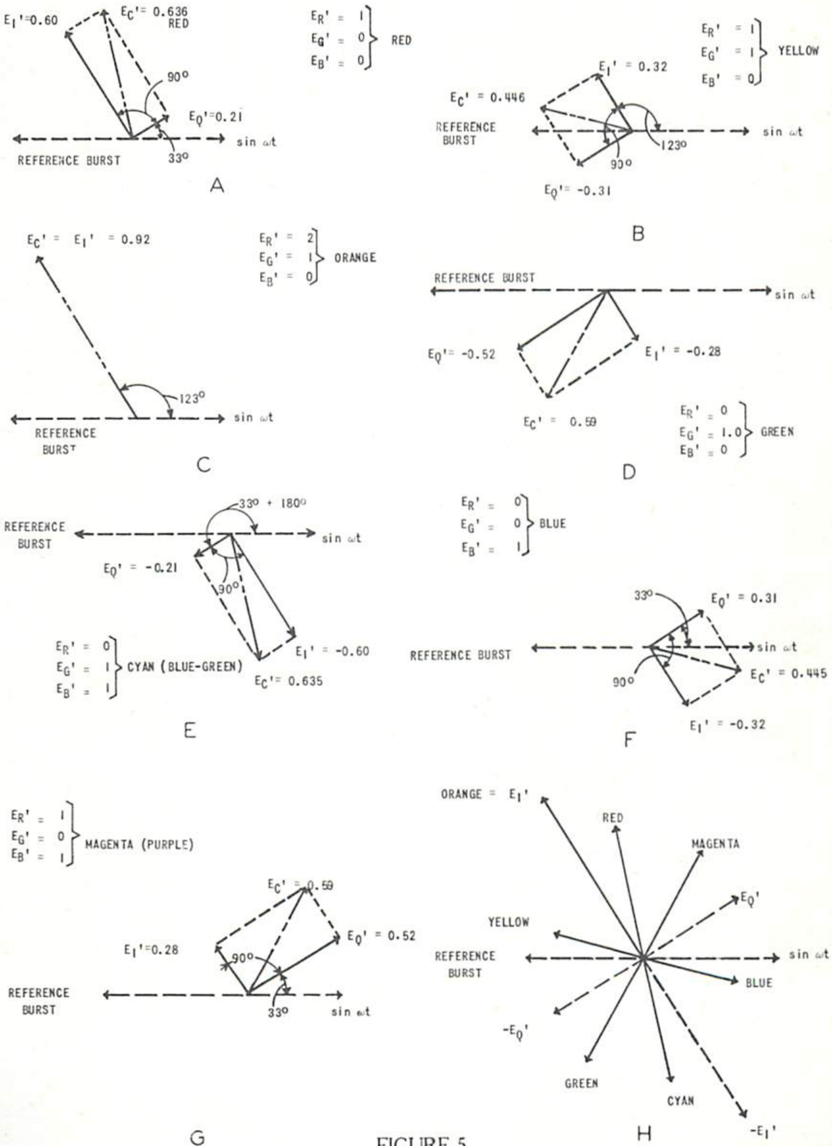

E_I'=0.60
E_C'= 0.636 RED
90°
E_Q'=0.21
33°
REFERENCE BURST
sin ωt
E_R' = 1
E_G' = 0
E_B' = 0
RED
A
E_R' = 1
E_G' = 1
E_B' = 0
YELLOW
E_I' = 0.32
E_C' = 0.446
REFERENCE BURST
123°
90°
sin ωt
E_Q'= -0.31
B
E_C' = E_I' = 0.92
E_R' = 2
E_G' = 1
E_B' = 0
ORANGE
123°
REFERENCE BURST
sin ωt
C
REFERENCE BURST
sin ωt
E_Q'= -0.52
E_I' = -0.28
E_C' = 0.59
E_R' = 0
E_G' = 1.0
E_B' = 0
GREEN
D
33° + 180°
REFERENCE BURST
sin ωt
E_Q' = -0.21
90°
E_R' = 0
E_G' = 1
E_B' = 1
CYAN (BLUE-GREEN)
E_I' = -0.60
E_C'= 0.635
E
E_R' = 0
E_G' = 0
E_B' = 1
BLUE
33°
E_Q' = 0.31
REFERENCE BURST
sin ωt
90°
E_C' = 0.445
E_I' = -0.32
F
E_R' = 1
E_G' = 0
E_B' = 1
MAGENTA (PURPLE)
E_C' = 0.59
E_Q' = 0.52
E_I'=0.28
90°
REFERENCE BURST
33°
sin ωt
G
ORANGE = E_I'
RED
MAGENTA
E_Q'
YELLOW
REFERENCE BURST
sin ωt
BLUE
-E_Q'
GREEN
CYAN
-E_I'
H

FIGURE 5

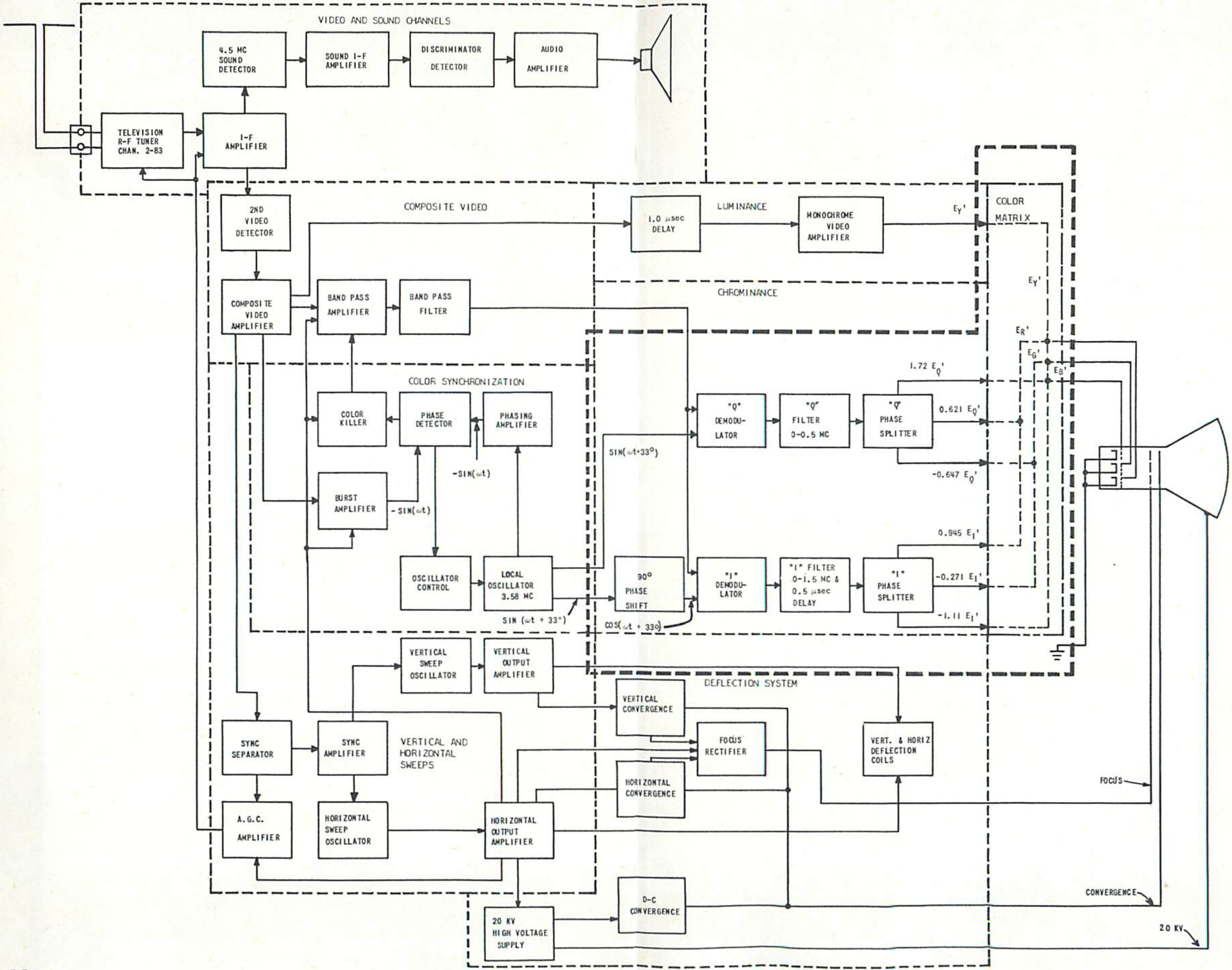
COLOR TO BE TRANSMITTED	E_R'	E_G'	E_B'	E_Y'	E_I'	E_Q'	E_C'
RED	1	0	0	0.30	0.60	0.21	0.636
YELLOW	1	1	0	0.89	0.32	-0.31	0.446
ORANGE	2	1	0	1.19	0.92	-0.1	0.92
GREEN	0	1	0	0.59	-0.28	-0.52	0.59
CYAN	0	1	1	0.70	-0.60	-0.21	0.635
BLUE	0	0	1	0.11	-0.32	0.31	0.445
MAGENTA	1	0	1	0.41	0.28	0.52	0.59
WHITE	1	1	1	1.0	0	0	0
BLACK	0	0	0	0	0	0	0

FIGURE 6

	1	2	3	4	5	6
E_R'	4.0	4.0	8.0	8.3	7.5	2
E_G'	4.0	2.0	4.0	5.0	0.5	4
E_B'	4.0	2.0	4.0	5.0	0.5	4
E_Y'	4.0	2.6	5.2	6.0	2.6	3.4
E_R-E_Y'	0	1.4	2.8	2.3	4.9	-1.4
$E_G'-E_Y'$	0	-0.6	-1.2	-1.0	-2.1	0.6
$E_B'-E_Y'$	0	-0.6	-1.2	-1.0	-2.1	0.6
E_Q'	0	0.42	0.84	0.7	1.5	-.42
E_I'	0	1.2	2.4	2.0	4.2	-1.2
E_C'	0	1.3	2.6	2.1	4.5	-1.3
SATURATION RATIO $\frac{E_C'}{E_Y'}$		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{7}{20}$	$\frac{9}{5}$	$\frac{13}{34}$
HUE RATIO $\frac{E_Q'}{E_I'}$		$\frac{7}{20}$	$\frac{7}{20}$	$\frac{7}{20}$	$\frac{7}{20}$	$\frac{7}{20}$

CHART 1

T4E-8


VIDEO AND SOUND CHANNELS
4.5 MC SOUND DETECTOR
SOUND I-F AMPLIFIER
DISCRIMINATOR DETECTOR
AUDIO AMPLIFIER
TELEVISION R-F TUNER CHAN. 2-83
I-F AMPLIFIER
2ND VIDEO DETECTOR
COMPOSITE VIDEO
1.0 μsec DELAY
LUMINANCE
MONOCHROME VIDEO AMPLIFIER
E_Y'
COLOR MATRIX
COMPOSITE VIDEO AMPLIFIER
BAND PASS AMPLIFIER
BAND PASS FILTER
CHROMINANCE
E_Y'
E_R'
E_G'
E_B'
COLOR SYNCHRONIZATION
1.72 E_Q'
COLOR KILLER
PHASE DETECTOR
PHASING AMPLIFIER
"Q" DEMODU-LATOR
"Q" FILTER 0-0.5 MC
"Q" PHASE SPLITTER
0.621 E_Q'
SIN(ωt+33°)
-SIN(ωt)
-0.647 E_Q'
BURST AMPLIFIER
- SIN(ωt)
0.945 E_I'
OSCILLATOR CONTROL
LOCAL OSCILLATOR 3.58 MC
90° PHASE SHIFT
"I" DEMODU-LATOR
"I" FILTER 0-1.5 MC & 0.5 μsec DELAY
"I" PHASE SPLITTER
-0.271 E_I'
-1.11 E_I'
SIN (ωt + 33°)
COS(ωt + 33°)
VERTICAL SWEEP OSCILLATOR
VERTICAL OUTPUT AMPLIFIER
DEFLECTION SYSTEM
VERTICAL CONVERGENCE
FOCUS RECTIFIER
VERT. & HORIZ DEFLECTION COILS
SYNC SEPARATOR
SYNC AMPLIFIER
VERTICAL AND HORIZONTAL SWEEPS
HORIZONTAL CONVERGENCE
FOCUS
A.G.C. AMPLIFIER
HORIZONTAL SWEEP OSCILLATOR
HORIZONTAL OUTPUT AMPLIFIER
D-C CONVERGENCE
CONVERGENCE
20 KV HIGH VOLTAGE SUPPLY
20 KV

A

FIGURE 7

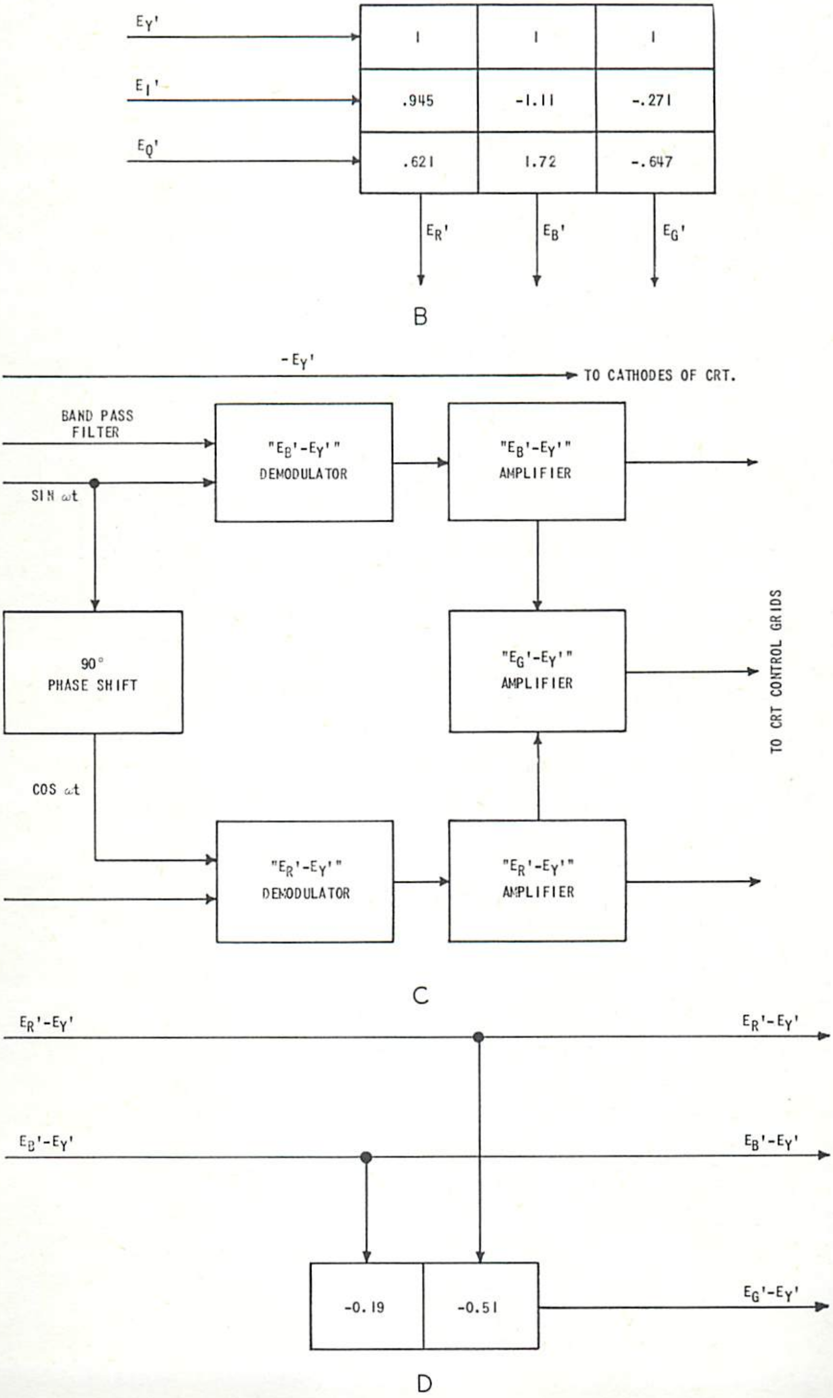

E_Y'
E_I'
E_Q'
1
1
1
.945
-1.11
-.271
.621
1.72
-.647
E_R'
E_B'
E_G'
B
$-E_Y'$
TO CATHODES OF CRT.
BAND PASS FILTER
SIN ωt
"$E_B'-E_Y'$" DEMODULATOR
"$E_B'-E_Y'$" AMPLIFIER
90° PHASE SHIFT
"$E_G'-E_Y'$" AMPLIFIER
TO CRT CONTROL GRIDS
COS ωt
"$E_R'-E_Y'$" DEMODULATOR
"$E_R'-E_Y'$" AMPLIFIER
C
$E_R'-E_Y'$
$E_R'-E_Y'$
$E_B'-E_Y'$
$E_B'-E_Y'$
-0.19
-0.51
$E_G'-E_Y'$
D

FIGURE 7

FROM OUR *Director's* NOTEBOOK

BE SPECIFIC

No employer is interested in a man who can "do ANYthing." He wants someone who can "do SOMEthing."

So be specific when you're asked what your qualifications are. "My training has been in TV servicing," or "I've done a bit of troubleshooting on radio receivers," are much better answers than, "Oh, I can handle almost anything in electronics."

The fellow who can do ANYthing is liable to end up on the business end of a broom, instead of on a job he has really prepared for.

Outline your qualifications carefully during an employment interview. You never can tell in advance when one particular phase of your training or experience might be just the very thing the employer is seeking.

Be specific. It pays!

Yours for success,

W. C. DeVry

DIRECTOR

PRINTED IN U.S.A.

T4